Local agro-ecological knowledge of sustainable intensification of the tree-crop-livestock system in the Ethiopian Highlands, Endamahoni Woreda, Tigray Region

Farmers in Belago settlement, Tsibet kebele in irrigated fields of *Impatiens tinctoria*

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Through action research and development partnerships, Africa RISING will create opportunities for smallholder farm households to move out of hunger and poverty through sustainably intensified farming systems that improve food, nutrition, and income security, particularly for women and children, and conserve or enhance the natural resource base.

The three regional projects are led by the International Institute of Tropical Agriculture (in West Africa and East and Southern Africa) and the International Livestock Research Institute (in the Ethiopian Highlands). The International Food Policy Research Institute leads the program's monitoring, evaluation and impact assessment. http://africa-rising.net/

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Glossary of community land types in Endamahoni

Community forest refers to mixed indigenous and exotic forests owned and protected by the community

Community grazing land refers to specific areas of pasture land left as natural grass land and open to the community to graze their livestock on

Community plantations refer to the plantations of *Cupressus lusitanica* and some eucalyptus which dates back to the Derg regime and are also owned and protected by the community

Particleboard factory land/ project land refers to eucalyptus plantations owned by a particleboard factory in Maychew town

Private eucalyptus woodlots refer to eucalyptus trees planted by farmers on private property

Livestock exclusion zones refer to specific areas (normally on the buffer of community forest land) that are patrolled to prevent livestock entering

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Introduction

Africa faces considerable challenges overcoming food insecurity in the coming decades. The decline in the natural resource base, on which agriculture depends, is significant. More than 95 million ha of arable land, or 75% of the total in sub-Saharan Africa has degraded or highly degraded soil, and farmers lose eight million tons of soil nutrients each year estimated to be worth $4 billion (Toenniessen et al. 2008). If present trends continue African food production systems will only be able to meet 13% of the continent's food needs by 2050 (Global Harvest Initiative, 2012; Montpellier Panel Report, 2013). One response to this challenge is sustainable intensification (SI). There are a number of definitions of SI but perhaps the most widely accepted definition comes from Pretty et al. (2011) which describes SI as '……producing more output from the same area of land while reducing the negative environmental impacts and at the same time increasing contributions to natural capital and the flow of environmental services'. Not surprisingly there are a number of challenges associated with moving SI from theory into practice within Africa – not least the considerable heterogeneity of African farming systems. Acknowledging this there remain questions about how SI will look like on the ground, and how it might differ amongst production systems, in different places, and given different demand trajectories.

SI is being developed as a 'systems' oriented approach to decision making which accommodates a mix of strategies required for different biophysical, social, cultural and economic contexts (McDermott et al. 2010). Given the high vulnerability of many African farming systems, it is important to recognise that capacity for SI will vary from shoring up resilience to enhancing productivity (Ginkel et al. 2013). SI strategies are only likely to be successful in areas were vulnerability has been addressed through resilience strategies.

Successful implementation of SI strategies needs to be implemented across a range of scales. One of the key constraints to implementation of SI in sub-saharan Africa is insufficient data at a local landscape scale. Prioritising where to implement SI interventions will require a sufficient characterisation of the variability in capacity of farming systems across these landscapes. Local ecological knowledge (LEK) is one tool for rapid characterisation of spatial and temporal variation within a landscape. LEK can also be used to identify trends and spatial patterns of land use and land cover change, observed by local people over many years, and the impact that these changes have wrought on ecosystem service provision (Pagella and Sinclair, 2014).

This study was focussed on identifying existing sustainable intensive agricultural methods in Endamahoni woreda, Tigray region. The study also collected local knowledge on agricultural methods so as to assist in the development and implementation of appropriately adapted technologies to intensify production of crops, livelihood and household production without extending the areas subject to cultivation.

Research Objectives

The research objectives of the study were:

- To characterize agro-ecological knowledge of farmers in the Africa RISING project sites
- To identify and map out community resources
- To assess land use and livelihood strategies at the household level
- To characterise existing tree cover and assess the drivers of tree cover change
- To determine temporal variation in availability of provisioning services (income, fuel, livestock feed, crops, labour.)

Research Questions

The research questions posed were:

1. What constraints are there to agricultural production and what agro-ecological knowledge do farmers have about them and their solutions?
2. What is the range of land use and livelihood systems in the area?
3. How have the tree cover and the land use systems changed over time?
4. What functions and services do trees provide in these sites?
5. What are the main resources farmers utilize and when in the year are they available?

Methods

Study site selection

The sites in this study were pre-selected for the Africa RISING project based on a specific set of criteria. The study sites were delineated based on political/administrative boundaries. Four 'woredas' (districts) were therefore chosen as the size of woredas is large enough to encompass a range of bio-physically defined areas with contrasting farming systems and a range of social institutions. The selection of target woredas was done based on the following criteria:

- It has 25% or more area dedicated to wheat production
- It is one of the government selected AGP (Agricultural Growth Plan) woredas
- It has an annual rainfall of more than 600mm and an elevation greater than 1700 m.a.s.l

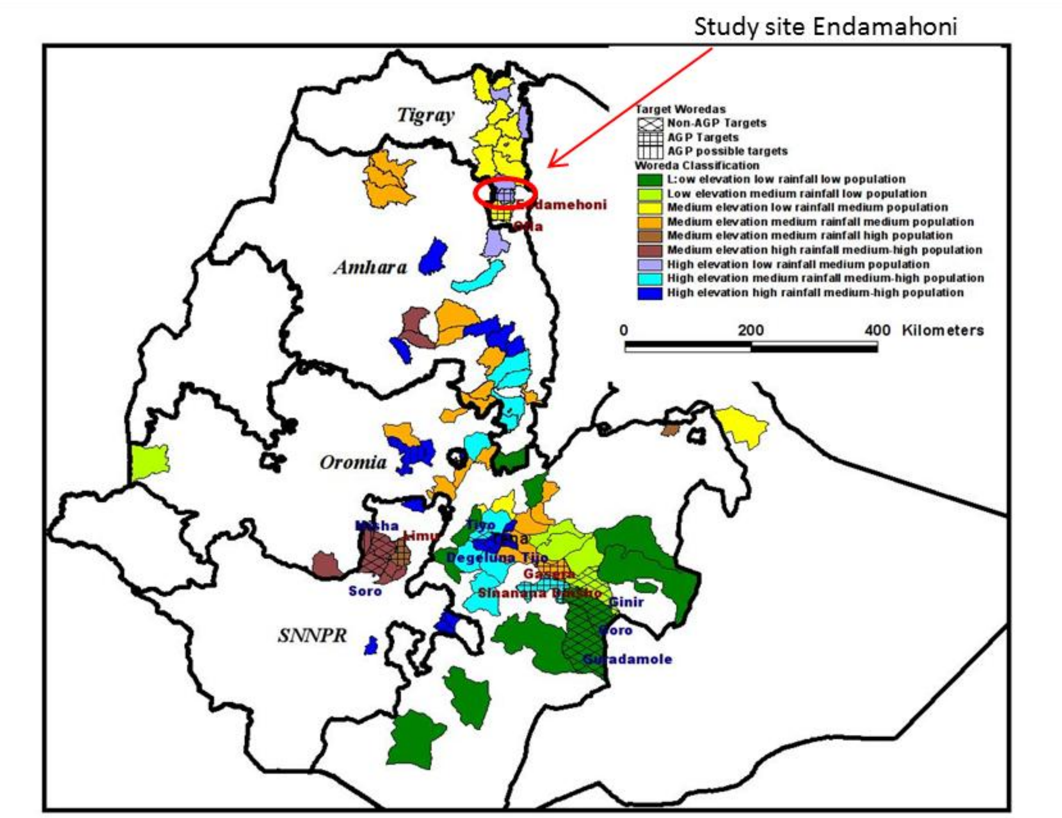

Figure 1 Classification of woredas and recommended target sites for Africa RISING Source: Legg, C. 2012 'Africa RISING the Ethiopian highlands mega-site selection of project implementation sites' ***Internal project report***

The chosen sites were known to exhibit large variations in existing levels of intensification including cereal-legume rotations and other crop-combinations and crop-livestock integration. Furthermore, the factors driving intensification such as agricultural potential, access to available technologies, demand for livestock products, and integration with markets were also known to vary. The sites were chosen to represent contrasting levels of intensification to enable the characterization of different trajectories and identification of technology combinations that lead to sustainable development pathways. The local knowledge research was conducted in order to better understand this variation and provide a richer characterization of the study sites at different scales.

Endamahoni woreda, located in Southern Tigray region, was selected as a highland wheat growing area with limited productivity and access to market. Below are statistics on land use types and population growth taken from the woreda office (Table 1). There may be inaccuracies in measuring land use cover, as well as differences in the definition of different land types (as the work was done at a kebele level).

Table 1 Table of land data taken from the DA offices in Tsibet and Embahazti kebele (source: Woreda office 2005 E.C)

Land use data	Tsibet	Embahazti
Total area	4016 ha	2071.79 ha
Rain-fed cropland	24.5%	27.2%
Irrigable cropland	1.3%	10.3%
Residential	7.2%	13.5%
Grazing land	3.2%	2.3%
Farmer eucalyptus	30%	3.8%
Company eucalyptus	22.8%	13.5%
Natural forest	9.8%	29.4%
Unutilized land	1.1%	
Total population	6311	4033
Human population density	1.6 per ha	1.9 per ha
No. of cattle	1294	2098
Cattle population density	10.1 c/per/ha	41.1 c/per/ha

Methodology

In this study the local knowledge of farmers and extension workers was acquired using the Agro-ecological Knowledge Toolkit (AKT5) knowledge-based systems methodology and software (Sinclair and Walker 1998; Walker and Sinclair, 1998; Dixon et al., 2001). The major focus of knowledge collection comprises an iterative cycle – that is eliciting knowledge from a small purposive sample of farmers, through semi-structured interviews, and the representation and evaluation of the local knowledge obtained using an explicit knowledge-based systems approach. Each new round of interviews is informed by the previous evaluation cycle and the process is complete when further interviews do not result in a change to the knowledge base. The knowledge base remains a durable and accessible record of the knowledge acquired and can be subjected to validation in a generalization phase where key results are tested with a large random sample of informants to explore the occurrence and consistency of knowledge amongst the wider populations of the research communities (Walker and Sinclair, 1998).

Field activities included transect walks, focus group discussions and a range of participatory methods used to complement the AKT methodology (Table 2). Farmers were selected across two kebeles in the Endamahoni woreda. Mapping exercises were carried out with groups of farmers as well as individual farmers of both genders (Plate 2).

Table 2 Activities in performed in the field to complement the AKT methodology

Activity	Tsibet	Embahazti
Landscape characterisation	Walks/ photographs	Walks/ photographs
Interview NRM Development Agent	1 SSI	1 SSI
Participatory resource mapping	1 FGD (m) and 2 SSI (f)	1 FGD (m) and 2SSI (f)
Historical timeline	1 FGD (m)	1 FGD (m/f)
First interviews farmers	7 SSI (m/f)	9 SSI (m/f/y)
Second interviews farmers	-	-
Seasonal cropping calendar	7 SSI (m/f)	8 SSI (m/f)
Livestock feed calendar	7 SSI (m/f)	9 SSI (m/f/y)
Land use and livelihood	7 SSI (2 FHH, 5MHH)	8 SSI (3FHH, 5MHH)
Nursery survey	Record species list/ means of distribution/ farmer preferences	
Other stakeholder interviews	1 SSI with particleboard factory forestry dept.	
Feedback discussion	1 FGD (m/f)	1 FGD (m/f)

KEY: X= activity performed, FGD=Focus Group Discussions, SSI=Semi Structured Interviews, m=male informants, f=female informants, y=youth informant, FHH=female head of household, MHH=male head of household

Plate 1 Interviews conducted on farmers' fields (top left), tree nursery visits (top right), focus group discussions (bottom right) and transect walks with development agents (bottom left). Photographs taken by M. Cronin and G. Gebru, July-August 2013.

Stratification

The following stratification categories were used to sample farmers for participation in both individual interviews and focus group discussions.

- Gender of informant
- Gender of household head
- Location in landscape
- Age (for historical timeline exercise only)

In Endamahoni a total of 50 farmers were involved in the study with 16 farmers involved in individual interviews and the remaining 34 farmers involved in four focus group discussions (Table 3). Location was an important consideration to account for variation in topography and soil types and land use practices in the upper catchment compared to the mid and lower catchment of kebeles. Gender was another consideration because of the different roles and responsibilities held by male and female farmers. Gender roles were found to be quite distinct and uniform in agricultural production, with men involved more heavily in ploughing and women in sowing, both were involved in weeding and harvesting. Gender of the household head was considered because of general trends in access to training and knowledge as well as the wealth status of the household. Female heads of household (in particular divorced women) tended to have less resources than typical male headed households.

Table 3 Breakdown of stratification categories for local knowledge research from Endamahoni woreda (informants from both individual interviews and purposively sampled focus groups).

	Location	Male(MHH)	Female (MHH)	Female (FHH)	age > 45	age < 16		
Endamahoni	Upper catchment	5	0	3	0	0	**Total Upper**	**8**
	Mid catchment	17	0	2	5	0	**Total Mid**	**24**
	Lower catchment	7	2	3	5	1	**Total Low**	**18**
	Totals	**29**	**10**		**10**	**1**		

KEY: MHH=Male headed household, FHH=Female headed household

Feedback sessions were held in each of the two kebeles where the main findings of the research were reported back to the community (Plate 3) (40% of the total informants were involved in the feedback discussions). This was done for validation and clarification of the results and to maintain transparency and full stakeholder participation in the field work. Participants from the focus groups and individual interviews were invited to participate.

Plate 2 Feedback sessions in Tsibet and Embahazti woredas. Photographs taken by M. Cronin, August 2013.

Results for Endamahoni woreda

Summary

A knowledge base was created to process the data taken from interviews and focus group discussions. A total of 156 statements were created (Table 4).

Table 4 Output from the Endamahoni kb showing number of statements of each type and number of statements with conditions attached.

TYPE	Number of statements	Conditions attached
all	151	86
attribute	5	3
causal	133	81
comparison	13	2
link	0	0

Statements were arranged into topics which represent the main findings of the study. In the Endamahoni knowledge base the topics were created around land use types and tree utilities (Table 5).

Table 5 Output from the Endamahoni kb showing the topics and the number of statements in each topic.

Topic	Statements
knowledge about fuel sources	26
knowledge of community forests	13
knowledge of home compounds	5
knowledge of irrigated cropland	12
knowledge of project land	13
tree_utilities	8

Community resource maping

The research in Endamahoni woreda was conducted in two kebeles, Embahazti and Tsibet. The landscape of both kebeles is topographically variable with high sandstone mountain tops, varying gradients of slopes and some flat valley bottoms. In order to identify and map community resources participatory resource mapping exercises were performed with farmers purposely selected with the assistance of development agents. Three to four farmers (mostly male heads of household) were selected from each settlement area of the two kebeles for the focus group. In Embahazti kebele the settlement areas were: Kola (lower catchment), Dega, Bolonta (mid catchment) and Adi Tsigeba (upper catchment). In Tsibet kebele the settlement areas were: Belago (lower catchment), Grahaile (mid catchment) Shemat and Tsibet (upper catchment). Farmers were asked to draw their settlements (Figure 2) to show the placement of resources in the village and the relative distances between resources (as measured in walking time). A total of eight settlement maps were produced by the farmers and two maps were constructed on the kebele level by the research team. The mapped results from the settlements showed that there were differences in the number and variety of resources and in their spread and accessibility both between the upper and lower catchment areas within a kebele and between the Embahazti and Tsibet kebeles. Some of these differences are stated below (taken from the knowledge base):

143: the altitude of Tsibet kebele villages is greater than Embahazti kebele villages

141: the dispersal of population of Embahazti kebele villages is greater than Tsibet kebele villages
139: the access to grazing land of the Tsibet kebele is greater than the Embahazti kebele
144: the amount of hybrid cattle of Embahazti kebele is greater than the Tsibet kebele
140: the fields adjacent to home compound of Embahazti kebele is greater than in the Tsibet kebele
142: the access to irrigated land of lower catchment is greater than upper catchment

Following are two examples of resource maps (Figure 2) from the lowest settlement area, Kola in Embahazti kebele, and the highest settlement, Tsibet in Tsibet kebele. These were chosen because they show the greatest difference in resources. The substantive conclusions from these mapping exercises are set down below.

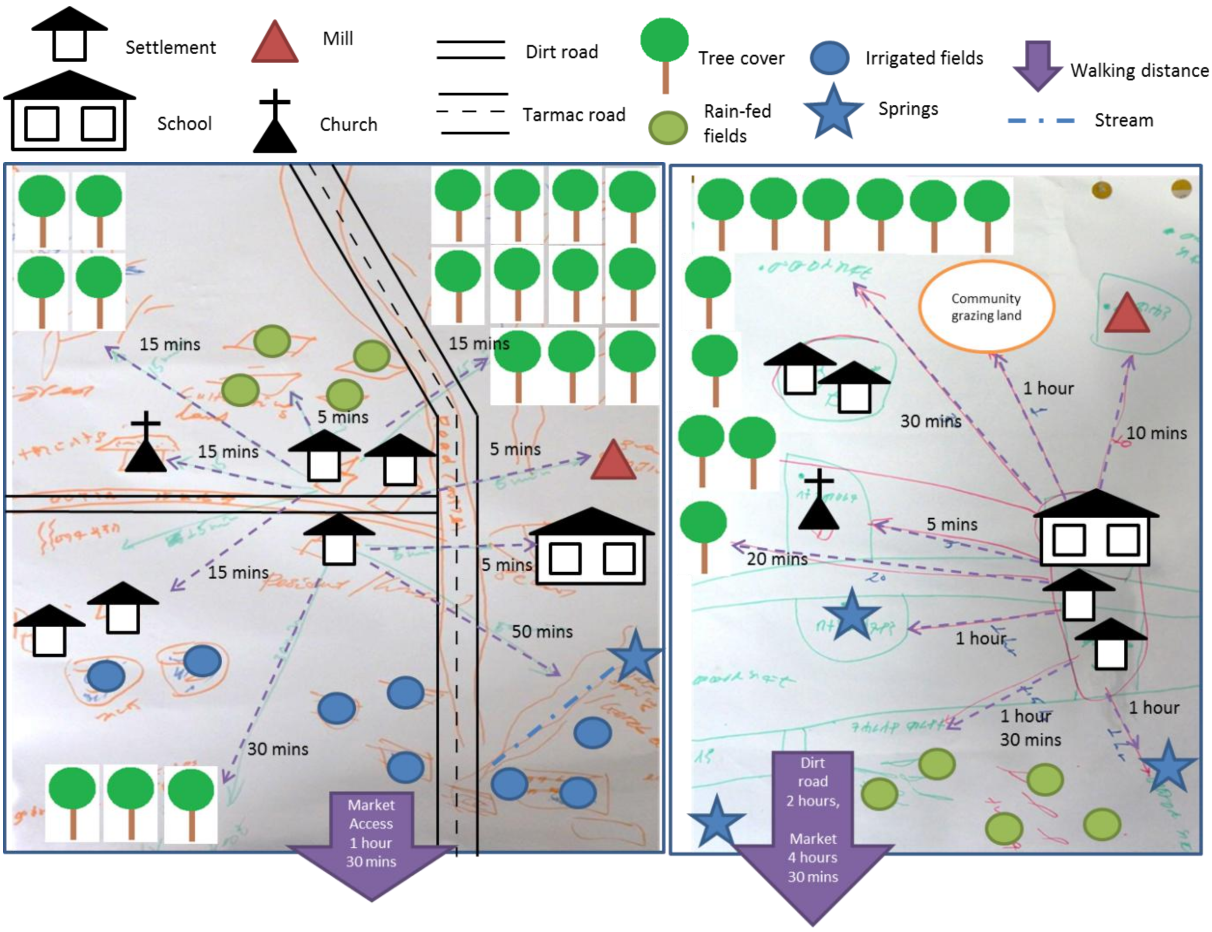

Figure 2 Participatory resource map from Embahazti kebele, Kola settlement in the lower catchment. Participatory resource map from Tsibet kebele, Tsibet settlement in the upper catchment area.

The lower catchment settlement of Kola had a new tarmac road (part of the link from Mekelle to Maychew) running through it. It was the closest settlement to Maychew town and the market (around 1 hour 30 mins walk along the road, quicker by footpath). The farmers stated that its population was dispersed with one or two households and scattered settlements along the road. It was topographically varied, comprising valley bottoms and steep slopes which were mostly terraced (although terracing was incomplete). It had a main stream and one spring and irrigated land which drew water from hand-dug wells and diversions of the stream and run-off. It had two types of tree cover, namely private Eucalyptus woodlots owned by farmers and company managed plantations of Eucalyptus run by a particleboard company in Maychew town. It had no community grazing land, as this land was redistributed one year ago to landless youth for cultivation (due to existing pressures on farmland).

The upper catchment settlement of Tsibet had no direct vehicle access and the closest road was a dirt road which ended two hours walk from the village. The nearest market was in Maychew town, a reported 4.5 hours walk by footpaths. The route to town was mountainous and steep so farmers capacity to transport goods was limited to using pack animal. Farmers described a distinct settlement area with a village centre and a less dispersed population. Tsibet settlement is located close to the Peak of Tsibet Mountain (3,900 m.a.s.l) and was topographically steep and mountainous. It had numerous spring headwaters but no irrigated land because of insufficient run-off. It had three types of tree cover; private Eucalyptus woodlots owned by farmers, plantations of Eucalyptus run by a particleboard company (accessed from the far side of Tsibet mountain) and community forests of a mixture of indigenous (mostly *Erica arborea* and *Juniperus procera*) and Eucalyptus trees. It also had community grazing land, (an area of natural grassland and an agreement for free grazing practiced in the community forest).

Household level resource mapping

Resources were also discussed at a household level during the individual interviews with farmers. Information was gathered on household agricultural landholding size and the spatial arrangement and direction of land parcels. Household level maps were also drawn by the farmers. A sample of the answers from those interviewed from the different strata is summarized below (Table 6).

Table 6 Characterisation of landholdings from farmers in different stratas (taken from interview notes)

	Parcel 1				Parcel 2			
	Plot type	**Size (ha)**	**Walking distance**	**Direction**	**Plot type**	**Size (ha)**	**Walking distance**	**Direction**
Tsibet Kebele	Rainfed/ terraced	0.5	30 mins	Uphill	Rainfed/ unterraced	0.5	1 hour	Uphill
Embahazti kebele	Irrigated	0.5	0 mins	Adjacent	Rainfed/ terraced	0.5	15 mins	Uphill
Male head	Rainfed/ terraced	0.25	7 mins	Parallel	Rainfed/ terraced	0.25	I hour	Downhill
Female head	Rainfed/ unterraced	0.25	30 mins	Uphill	n/a	n/a	n/a	n/a
Upper	Rainfed/ terraced	0.25	15 mins	Uphill	Rainfed/ terraced	0.25	30 mins	Parallel
Lower	Irrigated	0.125	10 mins	Parallel	Rainfed/ terraced	0.25	15 mins	Uphill

A pictorial representation was made of the table comparing and contrasting the different strata (Figure 3). The main points of comparison between the strata were:

- Tsibet kebele farmers were likely to have some distance between fields and home compounds (less dispersed population).
- There was more irrigated land in Embahazti and more farmers with land adjacent to home compounds (expand on implications)
- Male heads tended to own a larger landholding (especially when female heads were divorced) and much of the land given to divorced women was unterraced and newly distributed from community land
- Upper catchment land was more likely to be rainfed
- Lower catchment farmers had better access to irrigated land, though on average only owned a small amount

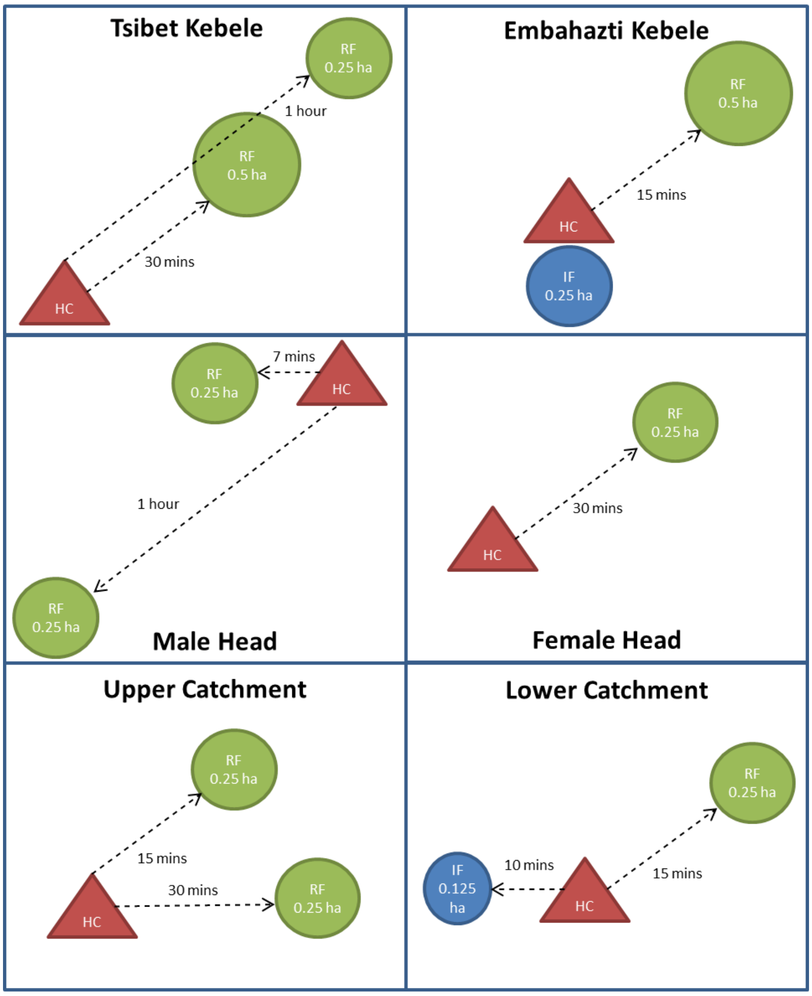

Figure 3 Pictorial representation of Table 4

KEY: HC = Home Compound, RF = Rain-fed Field, IF = Irrigated Field and arrows indicate walking distances and directions.

Land use and Livelihood strategies

Land Use and Livelihood diagrams were created using information taken from resource mapping on the community level (during the participatory resource mapping focus groups), resource mapping on a household level (done with women both FHH and wives of MHH) and interview notes from individual interviews. Four diagrams were made to better characterise the main strata – lower catchment, upper catchment, resource poor, resource wealthy.

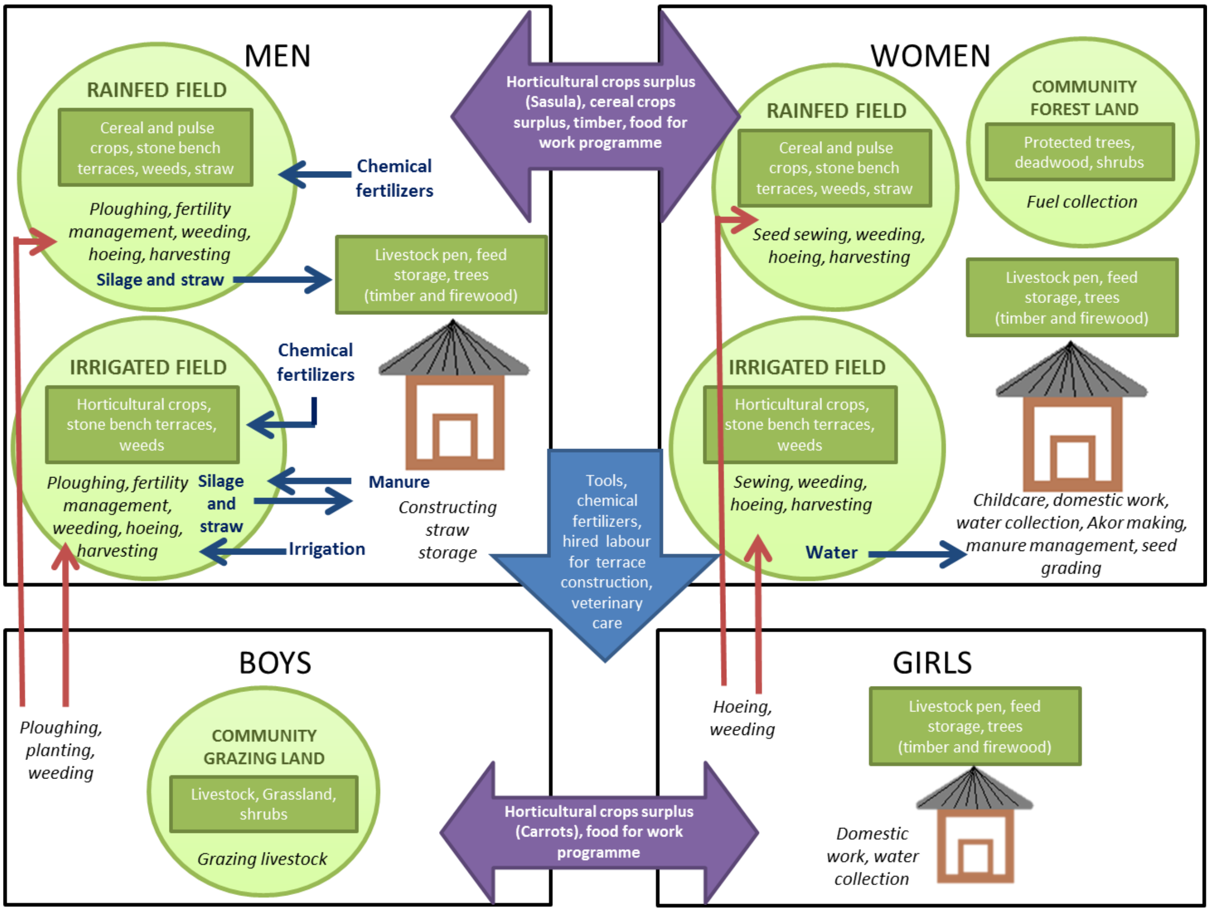

Figure 4 Land use and livelihood diagram for typical households in the lower catchment of the sites in Endamahoni woreda.

1. Lower catchment farmers (Figure 4)

The farmers in the lower catchment areas were tpically dependant on irrigated land/ horticultural crops as a source of income. The majority lived near irrigated land and had rainfed land at some distance from homestead. Children assisted in agricultural production during peak seasons (though spent most of their time at school) they also tended to sell surplus crops by the side of the main tarmac road to Maychew town. Very young children (from the age of 6 and up), and typically boys, would take livestock out to graze most days – the ‘community grazing land’ in the diagram can refer to all public land which children take the livestock to (such as roadsides, communal pasture and community forest).

Lower catchment settlements like Kola had few farmers with eucalyptus woodlots and so women were more heavily dependant on community forest deadwood and eucalyptus residues from the particleboard factory land, they also depended on ‘akor’ made from cow dung as fuel sources.

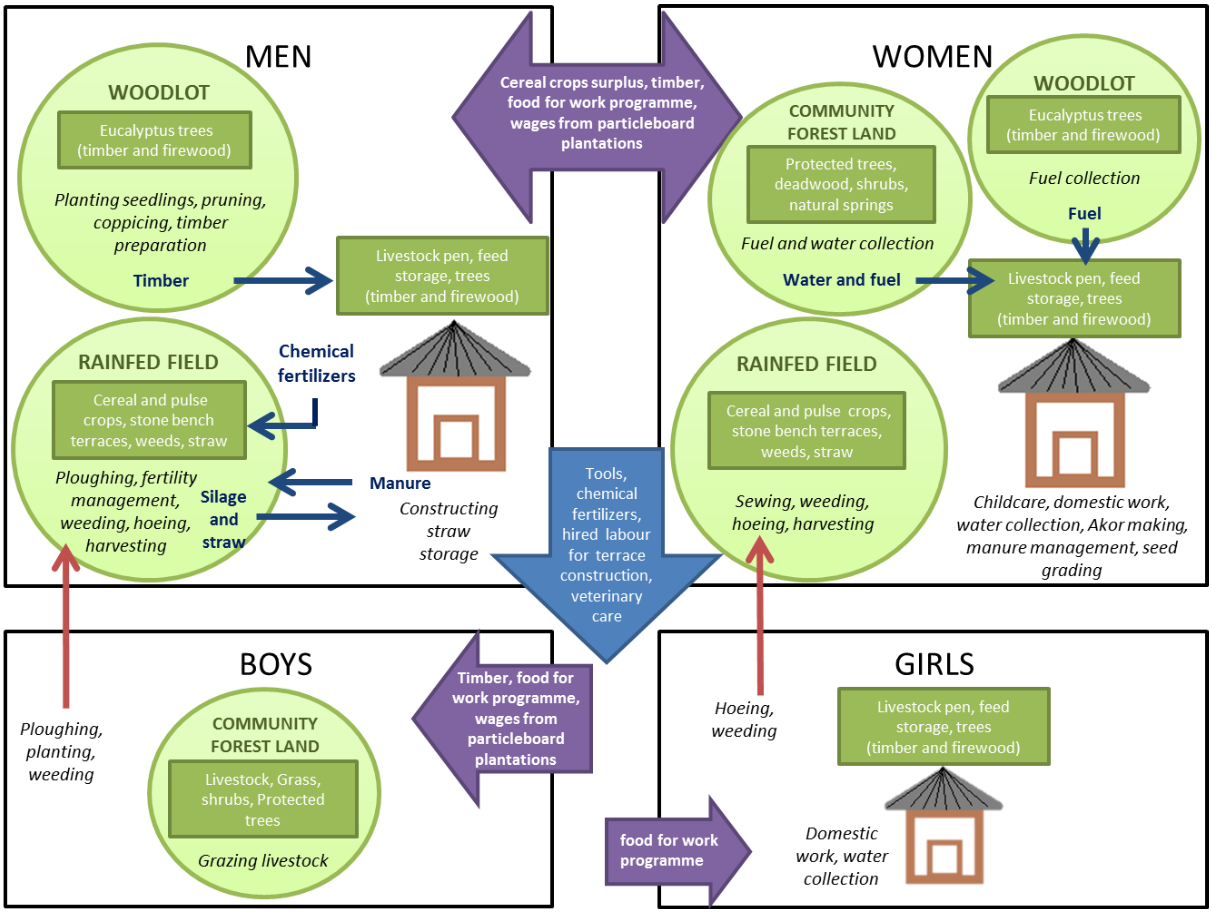

Figure 5 Land use and livelihood diagram for typical households in the upper catchment of the sites in Endamahoni woreda.

2. Upper catchment farmers (Figure 5)

Upper catchment farmers had similar labour flows to lower catchment, but differences in land use types available. Upper catchment farmers had no access to irrigated land and instead derived surplus income from eucalyptus woodlots. Eucalyptus would be managed as timber and be sold in Maychew town, women would use the byproducts and those which could not be sold for fuel. Farmers could own the equivalent amount of land to lower catchment farmers so the use of inputs was similar, however manure was only transported to fields close to the home compound. Labour requirements were reduced as irrigated land was continuously cultivated, and rainfed land had one cropping season. Some farmers derived extra income as hired labour and constructing roads and infrastructure in the government's Food for Work programme.

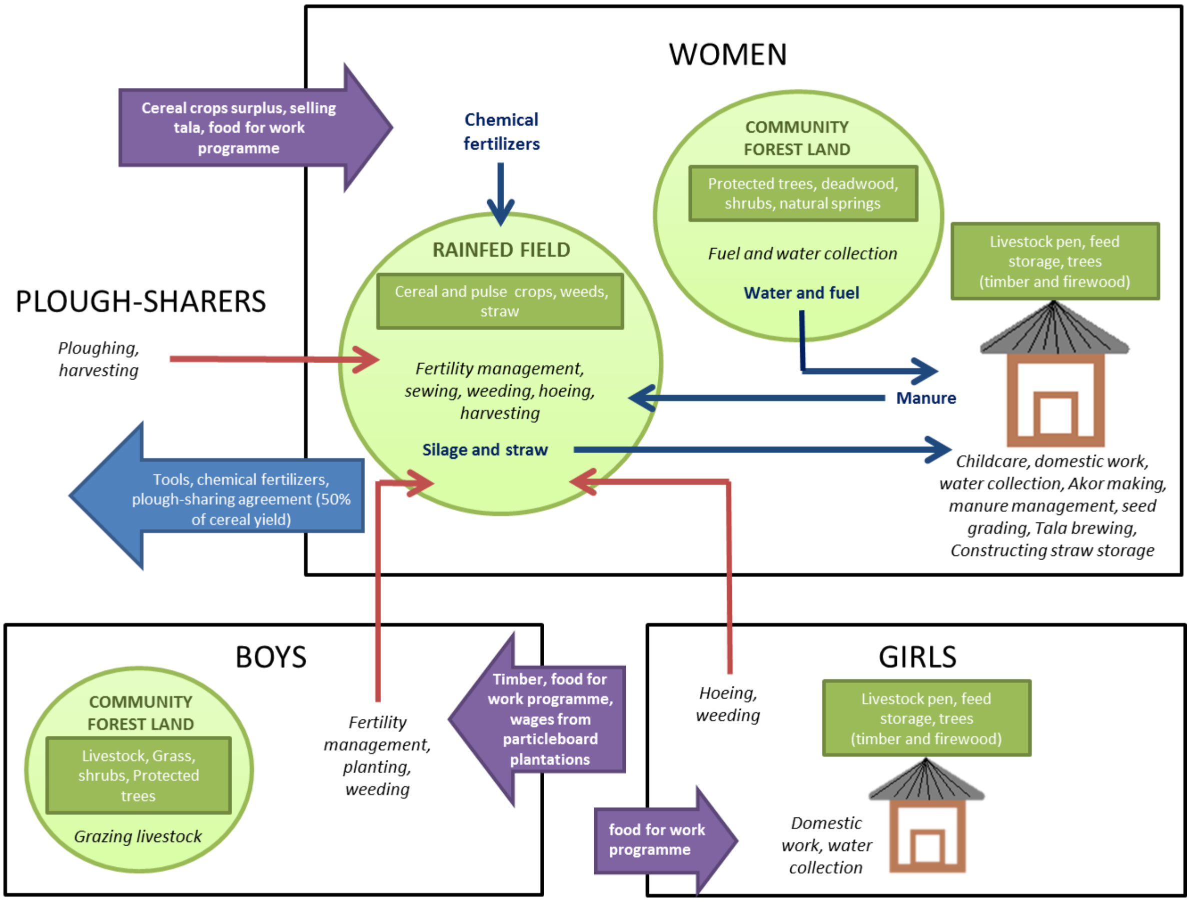

Figure 6 Land use and livelihood diagram for typical households who are resource poor and female headed in the sites in Endamahoni woreda.

3. Resource poor (Figure 6)

The strategy for characterising wealth indicators in this study was to concentrate on gender of the household head. Female headed households, in particular divorced women tended to have a markedly reduced access to resources both in labour capacity and in land ownership. They tended to have a smaller family labour force to depend on, and so would use plough-sharing as a means to cope with labour requirements. Plough sharing was a system in which neighbours and families with a surplus of labour or oxen, would plough others fields and assist with the agricultural labour in exchange for a percentage of the yield. Many divorced women owned only small ruminant livestock which produced insufficient manure to use as fertilizer. They were heavily dependent on community land (both for grazing livestock and for collecting fuel). Off-farm income from the Food for Work programme was also important as an income source as much of the agricultural labour was for subsistence only.

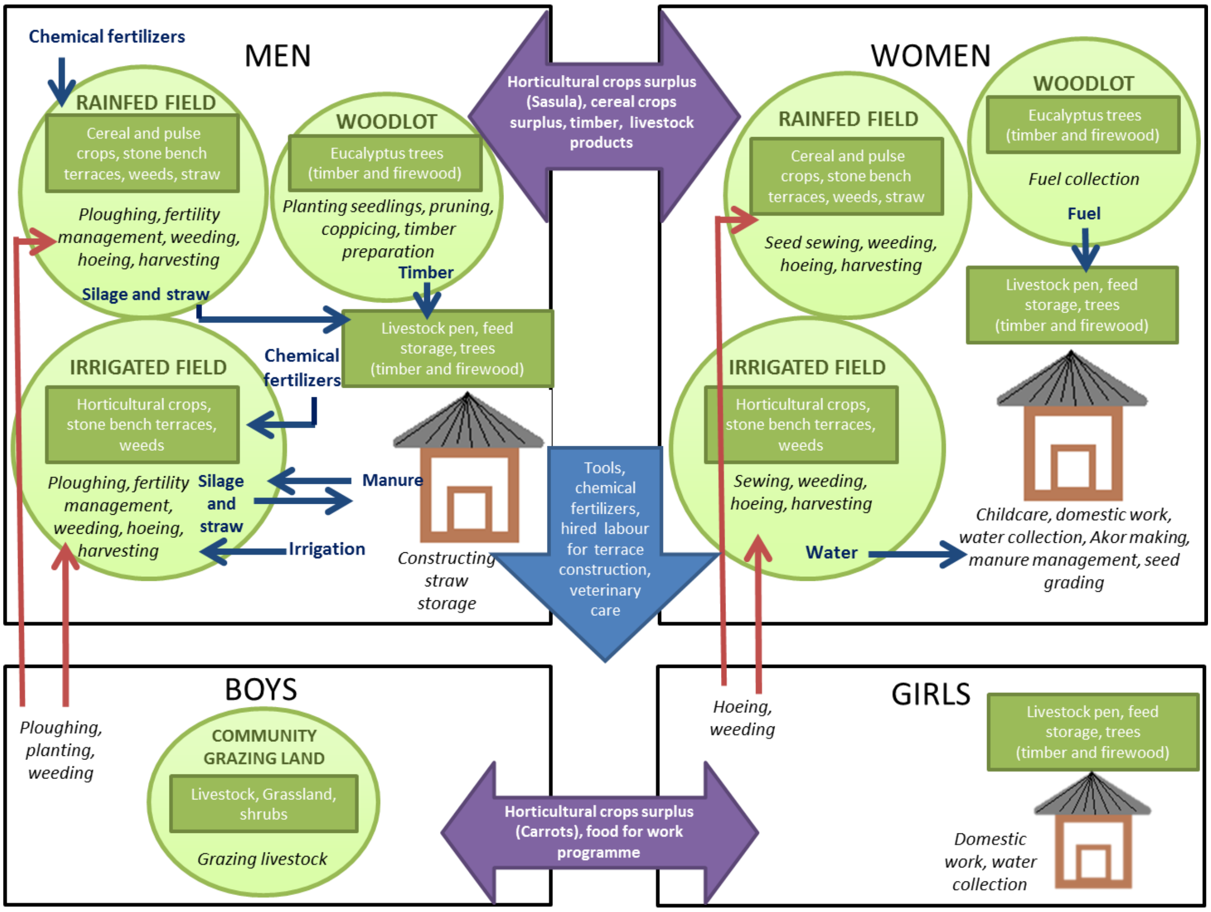

Figure 7 Land use and livelihood diagram for typical households who are resource rich in the sites in Endamahoni woreda.

4. Resource wealthy (Figure 7)

Resource wealthy farmers tended to own more land, have better access to training and new technologies, and also be more involved in niche income making enterprises. Many resource wealthy farmers were also 'model farmers' – a category developed by the government to better target training and technologies to willing or likely uptakers who also would have influence in the community to spread new ideas. Model farmers work in the 1-5 grouping system where the training they receive is spread by them to 5 non-model farmers in the hope of widespread uptake.

Table 7 Soil types and known attributes in Endamahoni Woreda, evidence taken from sources in the Endamahoni knowledge base.

	Distribution	Location	Topograpy	Texture	Weight	Dry texture	Depth	Soil water inflitration	Ploughing frequency
Black Walka	Dominanat	Upper to lower catchment	Levelled terraces	Clay loam	Heavy	Cracking	Deep	Prone to waterlogging	3 to 4
Red Walka	Dominanat	Upper to lower catchment	Levelled terraces	Clay loam	Heavy	Cracking	Deep	Prone to waterlogging	2 to 3
Bakael	Minor	Mid catchment	Sloped land	Clay	Heavy	Cracking	Deep	Prone to waterlogging	3 to 4
Hamad Kuarya	Minor	Mid catchment	Levelled terraces	Sandy loam	Mid	Soft	Medium	Mid drainage	2
Hutsa	Minor	Lower catchment	Flat valley bottom	Silt sand	Light	Soft	Shallow	High drainage	2

Table 8 Cropping calendar showing the dominant rainfed and irrigated crops for human consumption taken from sources in the Endamahoni knowledge base.

	January		February		March		April		May		June		July		August		September		October		November		December	
Wheat										P	P		W	W	W	W	W	W		H	H			
Barley										P	P		W	W	W	W		H	H					
Fava bean										P		W	W	W	W	W	W		H					
Sasula								P	P		W		W			W		H	H					
Potato										P	P	W	W	W	W	H	H							
Carrot		W			W		H	P		W			W		H	P		W			W		H	P

KEY: P = Planting, W = Weeding and H = Harvesting.

Agricultural cropping system

Soils in the area were found to be mostly clay based with some sand and silt deposited from the mountain tops. The lower areas of the kebeles had some flatland with vertisols. The mid land areas of the kebeles had variable slopes dominated by cambisols (with some vertisols). Typical features of the five soil types which were known can be found in the table below (Table 7).

Soil types in this region were named and classified by farmers during the participatory resource mapping exercises. They were then discussed in more detail during individual interviews. Soil types had common locations associated with them (upper, mid or lower catchments) were these soils observed. The silt and sandy loam soils were also associated with riverbanks and floodplain areas. The classification of soils was found to be very well understood in the community and the names used are consistent with these same types in other regions of Tigray.

Endamahoni woreda was situated in a uni-modal rainfall area where crops were mostly grown between late May and mid-November (Table 8). The prevalence of irrigated land allowed farmers to also cultivate crops out of these seasons. A calendar of cropping seasons and agricultural activities was made during SSI with individual farmers – labour trends and times of cropping were found to be consistent (variation only occurred in years when the rain was delayed. Rain-fed land was dominant crop land in both kebeles and characterized by shallow stone faced terraces constructed along contours. Farmers mainly grew cereal crops (wheat and barley) with some legumes on this land. Fields were characteristically small, fragmented and narrow. Tree features were rare.

Plate 3 Irrigated fields in Tsibet kebele, Belago settlement; newly terraced fields distributed to landless youth in Embahazti kebele Bolonta and Kola settlements. Photographs taken by M. Cronin, July 2013.

Irrigated land was valued highly by farmers and was mostly seen in the mid and lower catchment settlements (Plate 3). It was the most bio-diverse and intensively managed cropland. Farmers derived significant income from irrigated crops like “Sasula” (*Impatiens tinctoria*) which had a strong external market. The source of irrigation is from groundwater which farmers access using hand-dug wells. Some amount of surface water is also utilized by farmers from diverted springs and streams. The hand dug wells can be privately or publically owned and are constructed using local stone which is known to allow water percolation. The surface water sources were publically owned and managed by the community. Many of the surface water sources had cement lined channels and adequate water storage which were known by farmers to prevent water percolation.

Row planting

Row planting was a technique newly introduced to farmers by extension agents and the agricultural reseach centre in Alemata which was known to increase productivity of a field by better enabling weeding and increasing accuracy of fertilizer application, whilst reducing the amount of seed planted. Those farmers found practicing this technique were mostly model farmers. Row planting was not a commonly practiced technique as the information about it was only recently circulated in the community. Farmers expressed reservations concerning the increased labor required to plant their crops in rows and indicated that they were yet to be convinced about the increase in yield. Row planting was used in the participatory trial experiments organized by CIP as part of the Africa RISING project which was helping to increase farmer's awareness of the technique (Plate 4). The Farmer Training Centres of both kebeles also had row planting experiments running.

Plate 4 A participatory trial site for different varieties of fava bean and potato planted on a farmer's field. Photograph taken by M. Cronin, August 2013.

Crop rotation and intercropping

As previously stated the irrigated land proved to be the most bio-diverse. Farmers characteristically utilized this land to grow a wide range of horticultural crops as well as fruit trees (*Malus domesitca*) and fodder crops (*Pennisetum spp.,* maize) (Plate 5). The compatibility of crops for companion planting as well as the effect a crop had on the soil and the subsequent productivity of another crop was well understood by farmers with irrigated land.

Plate 5 Intercropping on irrigated land adjacent to a home compound including an apple tree, cabbage, sasula and potatoes; patches of different crop types in a rotation system on fragmented irrigated land. Photograph taken by M. Cronin

Soil and water interactions

Farmers were found to have rich explanatory knowledge concerning the drivers of land use change over time and the subsequent agro-ecological processes which have arisen from these changes. A causal diagram was developed in the Endamahoni knowledge base which highlights some of the main drivers identified by farmers which have affected the soil and water resources in both Tsibet and Embahazti kebeles (Figure 8). These main drivers include changes in the political regime and policy, the distribution of land during the Derg regime, the distribution of community land over the last decade, and population growth.

The loss of indigenous tree cover was stated to have occurred during the Haile Selassie regime when forest regulation was 'light touch'. According to the farmers consulted the loss of this tree cover led to an increase in surface run-off and soil erosion as well as an increase in river flow. According to the farmers interviewed, during this regimethe river was heavily polluted with sediment during the rainy season and the level of the water would become too high to cross. Over time the amount of sedimentation and river flow has decreased because of the reforestation programme established by the Derg government. During the Derg administration eucalyptus and cypress were planted in the areas most vulnerable to erosion.

Farmers observed recent changes in rainfall distribution where the duration of the rainy season appears to be shrinking and noted that this has also reduced river flow. Farmers also link the increasing exploitation of groundwater and surface water for irrigation as a factor influencing river flow (notwithstanding that this irrigation also increases annual crop yields). Farmers stated that the consequence of increasing irrigated land is field exhaustion due to continuous cultivation; a decline in soil fertility and a consequential reliance on fertilizer inputs from livestock and from chemicals.

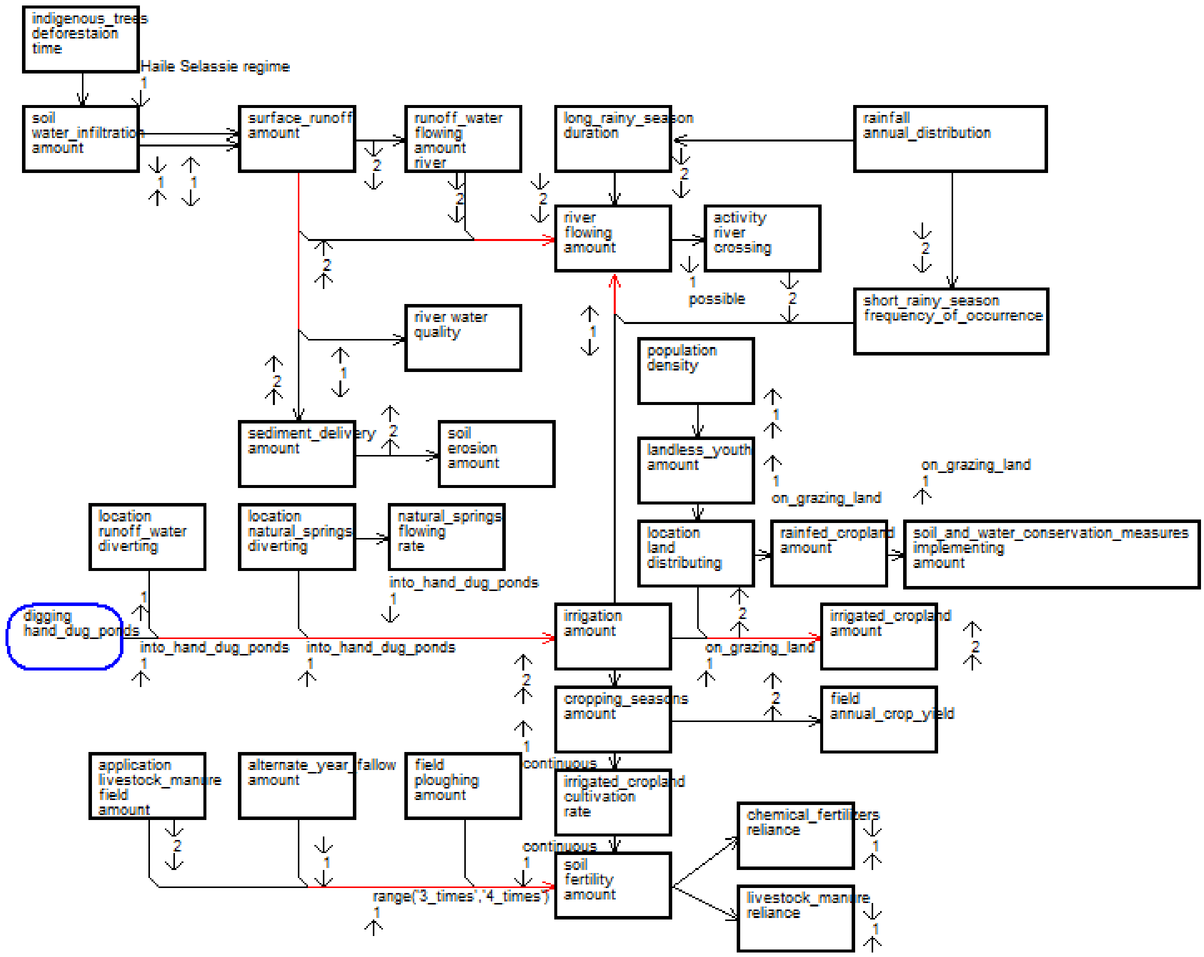

Figure 8 Causal diagram on the impacts of land use change on soil and water resources in Endamahoni Woreda.

KEY: Nodes represent natural processes (ovals), or attributes of objects, processes or actions. Arrows connecting nodes show the direction of causal influence. The first small arrow on a link indicates either an increase (↑) or decrease (↓) in the causal node, and the second refers to the effect node. Numbers between small arrows indicate whether the relationship is two-way (2), in which case an increase in A causing a decrease in B also implies that a decrease in A would cause an increase B, or one-way (1), where this reversibility does not apply.

Soil erosion appeared to be well understood by farmers and management to reduce erosion has been increasing in Endamahoni as part of the Farmer Safety Net Programme. In this programme the government targeted and provides wage supplements to farmers in food insecure areas in the Tigray region. Farmers have therefore been employed in the construction of soil and water structures and are thus paid by the government to construct stone bench terraces and stone bunds. The government has also funded gabion construction in major gullies and nursery tree planting in livestock exclusion zones (only piloted in two settlement sites per kebele). The programme has funded the patrolling of livestock exclusion zones which is carried out by an appointed patrol (a farmer from the local community) to prevent livestock damaging the terraces or browsing on the tree seedlings.The programme funds are limited but priority funding is allocated to terrace construction in certain newly distributed land (notably in steep scrubland where there is potential to cultivate crops. The following diagram shows the components of soil and water conservation measures taken in the sites and the conditions by which they were implemented.

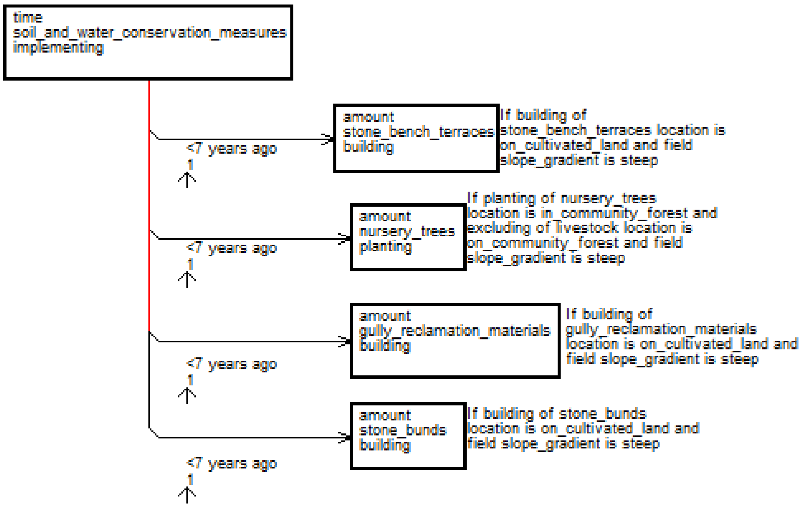

Figure 9 Soil and water conservation activities supervised by the NRM development agent and implemented through the Government funded Safety Net programme.

Tree nursery survey

Plate 6 Tree nursery on the outskirts of Maychew town, used by both Kebeles to source many of their timber and fodder trees; *Sesbania sesban* seedlings to be planted in newly distributed fields in Bolonta settlement, Embahazti kebele. Photographs taken by M. Cronin August 2013.

The biggest government run nursery which was used by both kebeles, was located on the outskirts of Maycew town (Plate 6). The majority of seedlings prepared in this nursery went to the development agents for planting in watershed sites and community lands. Development agents were also involved in using leguminous tree seedlings in areas where the government Food for Work Program is running to demonstrate intercropping techniques on terraced land for added income. Farmers were observed by nursery technicians to collect mostly Eucalyptus trees though there was increasing interest in fodder tree and grass species.

The following species were observed at the nursery site:

- *Juniperus procera*
- *Eucalyptus globulus*
- *Cupressus lusitanica*
- *Acacia decurrens*
- *cf. Chamaecytisus proliferus*

- *Sesbania sesban*

The following improved fodder grass species were observed at the nursery site:

- *Pennisetum purparium*
- *Chloris gayana*

Tree and shrub services, utilities and niches

As stated, one of the objectives of this study was to characterise existing tree cover, assess the drivers of tree cover change, to assess what functions and services trees provide in these sites and how the tree cover and the land use systems changed over time.

The starting point was to document the natural placement of trees. There were considerable altitudinal variations within and as between these sites. This affected tree cover. On these sites the only strategic planting was of eucalyptus trees.

Concerning this natural tree placement certain species for example the tree species *Acacia abyssinica*, *Maytenus undata*, *Dodonaea angustifolia*, *Dovyalis abyssinica* and *Leucas abyssinica* and the shrub species *Myrsine africana* and *Cadia purpurea* - were only to be found in lower catchment, others, namely *Hypericum revolutum*, *Salix subserrata*, *Ficus sur*, *Erica arborea*, *Hagenia abyssinica* and *Juniperus procera* were found only in the high mountain tops (Table 9). There was also some variation in vegetation, in particular, differences occurring where the land was inaccessible to livestock and therefore protected from livestock browsing pressure. The following table summarizes the local knowledge of the services, niches and abundance of local tree and shrub species.

Table 9 Output from the endamahoni KB using the AKT5 hierarchic object usage tool - table on the services, location and abundance of tree species in Endamahoni woreda.

				Provisioning services					Regulating services			Altitude		Common position in landscape									Abundance			
	Local name	***Scientific name***	***indigenous/ exotic***	Fuelwood	Timber	Livestock fodder	Dead fence	Live fence	Gully reclamation	Cropland erosion control	Watershed conservation	Lower catchment	Upper catchment	Livestock exclusion zones	Project land	Riparian	Cropland boundaries	Zero grazing Cropland	Home compound	Community forests	Community plantations	Grazing land	Naturally regenerating (browsing resistance)	Threatened	Common	Propagated
Trees	cheha	*Acacia abyssinica*	I			x						x												x		
	acacha	*Acacia decurrens*	E							x	x							x								x
	acacha	*Acacia saligna*	E							x	x			x				x								x
	chaa/ quiha	*Acacia seyal*	I			x	x				x	x	x	x		x	x			x		x	x		x	
	tumay	*Allophylus abyssinicus*	I									x	x							x					x	
	tsada kotsli	*Buddleja polystachya*	I									x	x							x					x	
	tree lusent/ lucrene	*cf. Chamaecytisus proliferus*	E			x			x	x	x							x				x				x
	shamfa	*cf. Ficus sur*	I										x							x				x		
	tsehedi ferenji	*Cupressus lusitanica*	E	x													x		x		x					x
	tahses	*Dodonaea angustifolia*	I								x	x		x						x			x			
	mongolhats	*Dovyalis abyssinica*	I			x						x										x		x		
	hasti	*Erica arborea*	I	x									x							x				x		
	bahir zaf	*Eucalyptus camaldulensis*	E	x	x		x								x	x	x		x		x		x		x	x
	bahir zaf	*Eucalyptus globulus*	E	x	x		x								x	x	x		x		x		x		x	x
	gravilea	*Grevillea robusta*	E								x	x														x
	habi	*Hagenia abyssinica*	I			x							x	x		x	x			x				x		
	abedi	*Hypericum revolutum*	I										x							x				x		
	tsehedi habesha	*Juniperus procera*	I	x	x						x		x	x		x	x		x	x		x			x	x
	tekuari	*Leucas abyssinica*	I			x						x										x			x	
	apple	*Malus domestica*	E							x		x						x								x
	tselim	*Maytenus undata*	I			x						x														
	shihnet	*Myrica salicifolia*	I									x							x	x				x		
	awlie	*Olea europaea subsp cuspidata*	I			x					x	x		x						x		x	x	x		x
	tetalo	*Rhus glutinosa*	I									x								x						
	hangro	*Salix subserrata*	I										x							x				x		
	sesbania	*Sesbania sesban*	I			x			x	x	x							x						x		x

Table 10 Output from the endamahoni kb using the AKT5 hierarchic object usage tool - table on the services, location and abundance of shrub species in Endamahoni woreda.

				Provisioning services					Regulating services			Altitude		Common position in landscape									Abundance			
	Local name	***Scientific name***	***indigenous/ exotic***	Fuelwood	Timber	Livestock fodder	Dead fence	Live fence	Gully reclamation	Cropland erosion control	Watershed conservation	Lower catchment	Upper catchment	Livestock exclusion zones	Project land	Riparian	Cropland boundaries	Zero grazing Cropland	Home compound	Community forests	Community plantations	Grazing land	Naturally regenerating (browsing resistance)	Threatened	Common	Propagated
Shrubs	tabeb	*Becium grandiflorum*	I	x							x	x	x				x		x				x		x	
	atsats	*c.f. Sogeretia thea*	I			x							x							x	x		x			
	shilen	*Cadia purpurea*	I			x						x								x	x		x		x	
	egam	*Carissa edulis*	I			x						x	x							x	x		x		x	
	alihim	*Discopodium penninervium*	I					x				x	x				x		x						x	
	dander	*Echinops macrochaetus*	I	x			x					x	x		x					x	x		x		x	
	beles habesha	*Euphorbia abyssinica*	I	x				x				x	x				x		x						x	
	kachmo	*Myrsine africana*	I			x						x								x	x		x		x	
	hohot	*Rumex nervosus*	I			x					x	x	x							x	x		x		x	
	ashiko		I					x				x					x		x						x	
	engule		I					x				x					x		x						x	

Tree crop interaction

Plate 7 Eucalyptus managed on short coppice rotation for fuel and planted in low densities on a wheat field in Tsibet kebele, Shemat settlement (left); Farmer training centre in Tsibet kebele with an example of leguminous tree intercropping which has been fenced off to protect from livestock (right). Photographs taken by M. Cronin, August 2013.

Concerning tree crop interactions farmers in these sites routinely noted that eucalyptus had negative effects on crop land (Plate 7). They reported problems from shading cast by the crown, the allelopathic effect of eucalyptus leaves and their root competition for nutrients and water. Farmers generally had insufficient knowledge on the compatibility of leguminous fodder trees with crops because the adoption of this recent technology was quite low (Plate 7). The areas where leguminous trees were found was irrigated land and fields adjacent to the home in Embahazti kebele.

Indigenous trees were not common on cropland but seen as having no effect on crop growth when pruned regularly. This was observed for *Juniperus procera* and *Acacia seyal*. *Malus domestica* was used as a cash crop and found in irrigated land in Embahazti kebele. It was also known to stabilise terraces with no negative effect on crop growth.

Farmers also commonly recognised a number of constraining factors affecting the level of integration of trees on cropland. Free grazing constrained the potential for intercropping trees on fields because farmers could not guarantee that neighbours animals would not destroy their trees during open grazing seasons. Exceptions to this were found to be in irrigated land, which is never open to livestock grazing and land close to the home compound which was easily monitored by the farmer. Another constraint was the small field sizes - narrow terracing reduced the space for possible planting.

Policy and fuel use

There are few tree and shrub species utilized by farmers as fuel and firewood (Tables 9 and 10). This was stated to be because of community bylaws which prohibit the cutting of trees in community land. Farmers followed these bylaws because of the recognized importance of community forest for soil conservation on the steep mountain slopes. When questioned, the farmers explained that if pruning was allowed the pressure on tree cover would be too great and the area would be deforested.

The farmers therefore mostly obtain their necessary fuel and firewood from eucalyptus trees or - the shrub species *Echinops macrochaetus* and *Becium grandiflorum* . There is a reliance on shrub residue and leaf and twig biomass for fuel and firewood. Again because of the laws, woody biomass is taken only from private woodlots of eucalyptus. These privately owned eucalyptus trees also serve as an income source for farmers, which reduces the proportion used as a fuel source as most of the biomass is sold as timber. The shrub species are naturally abundant and are harvested as deadwood, brash and residue from community land. The shrub residue, leaf and twig biomass is also available to be taken with approval from the particle board factory land.

Another significant fuel source was 'akor' made from cow dung. The use of dung as fuel was known to have a consequential affect on soil fertility as compost was the secondary function of dung in the sites. Dung is collected from the livestock pens within the home compound and made into flat discs and left to dry - dung from the dry season is preferred as it dries quickly.

Plate 8 Farmer carrying eucalyptus and *Echinops macrochaetus* dead biomass collected from the community forest to use as fuel in Embahazti kebele Adi Tsigeba settlement (left); a eucalyptus plantation (right). Photographs taken by M. Cronin, July 2013.

There was a recognized shortage of fuel sources and quality fuel in the two sites. The sources commonly utilized (including the cow dung) were known to be poor quality - fast burning and smoky - and these were linked with health and respiratory problems particularly experienced by women. A causal diagram from the knowledge base demonstrates how the implementation of community bylaws which restrict the cutting of trees on community land and the distribution of some community land to the eucalyptus particle board company has reduced the availability of fuel in the area (Figure 10).

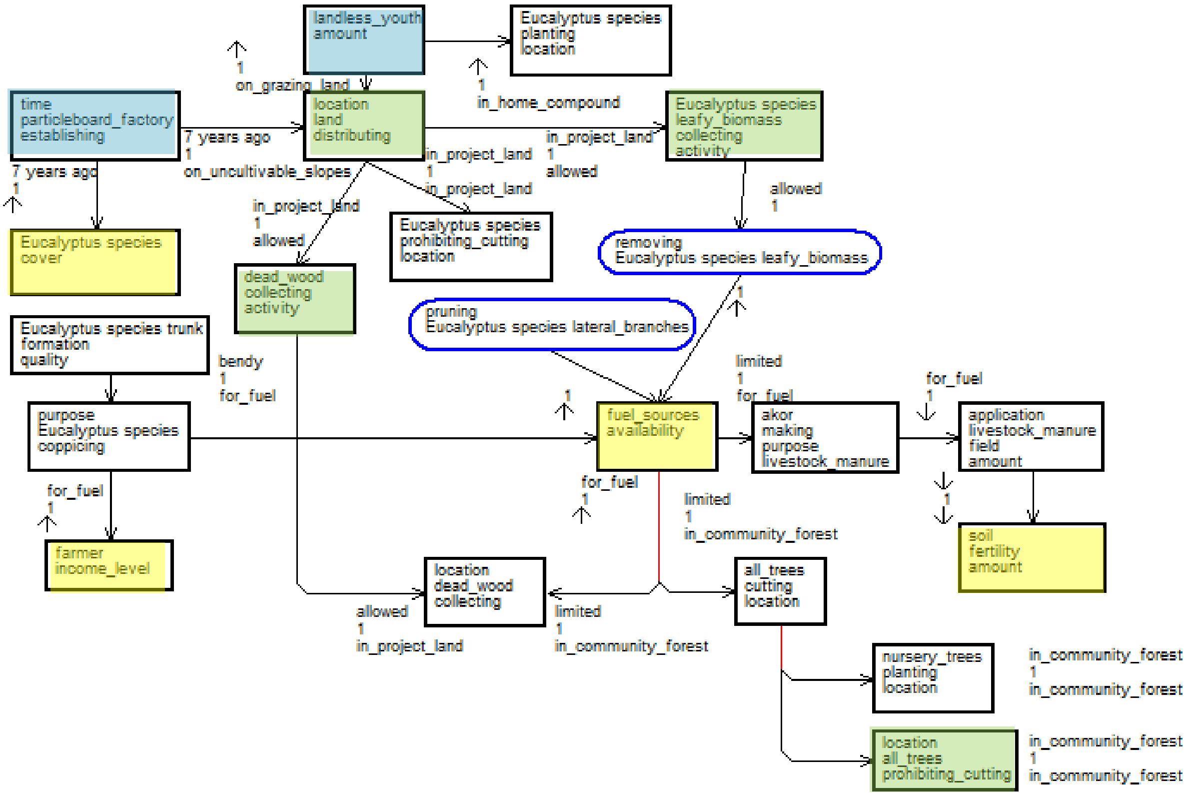

Figure 10 Causal diagram on the impacts of land use and policy changes to the availability of and management of fuel resources (see Figure 8 for key details). *Blue nodes indicate the key stakeholder driving changes, Green nodes indicate key policies driving changes, Yellow nodes indicate key consequences of these changes according to farmers

Livestock feed sources

 

Plate 9 Farmers weeding a barley field and removing grasses to feed directly to their livestock in Embahazti kebele, Dega settlement; woman cleaning collected grass weeds in the river to prepare as silage on the border between the two kebeles. Photographs taken by M. Cronin, August 2013.

Agricultural fields provide the majority of livestock feed sources (Table 11). Straw is made from crop residue which is collected and stored after harvesting crops and is fed to livestock throughout the year. Fresh grass weeds are collected by farmers over the crop growing period and fed to livestock immediately (Plate 9) and silage is made from any excess weeds which are dried and stored and fed to livestock in the dry season.

Exotic leguminous trees and grasses are known by farmers to be fast biomass producers which are highly palatable to livestock. Locally known exotic fodder trees and grasses include: *Chamaecytisus proliferus*, *Sesbania sesban*, *Pennisetum purparium* and *Chloris gayana* which were available in the tree nursery in Maychew town. When grown they provided feed for most of the year, and were managed to encourage rapid growth in the early rain season (Table 11). Growing these species was rare because farmers lack the space in their land and lack community mobilization collectively to protect leguminous species from livestock. Insufficient quantity and diversity of feed sources and insufficient space to plant improved feed types were therefore seen by farmers as the main problems with livestock productivity in this area.


Plate 10 Marginal land on the boundaries of fields being utilised for grazing in Tsibet kebele (left); Sesbania sesban fodder tree planted in a patrolled livestock exclusion zone in Tsibet kebele, Shemat settlement (right). Photographs taken by M. Cronin, July and August 2013.

Grazing sources

In the consultations farmers made clear that they recognize the value of the natural tree and shrub fodder sources because of their resilience to the local conditions. However none of the native species are managed for that service because of the bylaws restricting cutting of trees on community land. Instead these species are browsed by sheep and goats if they are accessible to livestock. Some tree and shrub species are particularly threatened by the open grazing system and because of over-grazing are only found in exclusion zones or inaccessible highlands.

Open grazing on agricultural land (excluding irrigated land) over the dry season provides a key resource for livestock during the feed scarce season. Most native sources of grass, tree and shrub fodder are highly pressured due to the changes in land use over time. Population pressures on land have caused the marginal land, roadsides and boundaries around fields to be utilised for grazing (Plate 10). A causal diagram from the knowledge base shows how the distribution of some community land (both grazing and forest land) to the eucalyptus particleboard company has also led to the establishment of laws which prohibit livestock from open grazing in particleboard land but enabled farmers to cut and carry grasses instead. Cut and carry potential in this land is limited because of the competitiveness of eucalyptus which has out-competed the grass and shrub species.

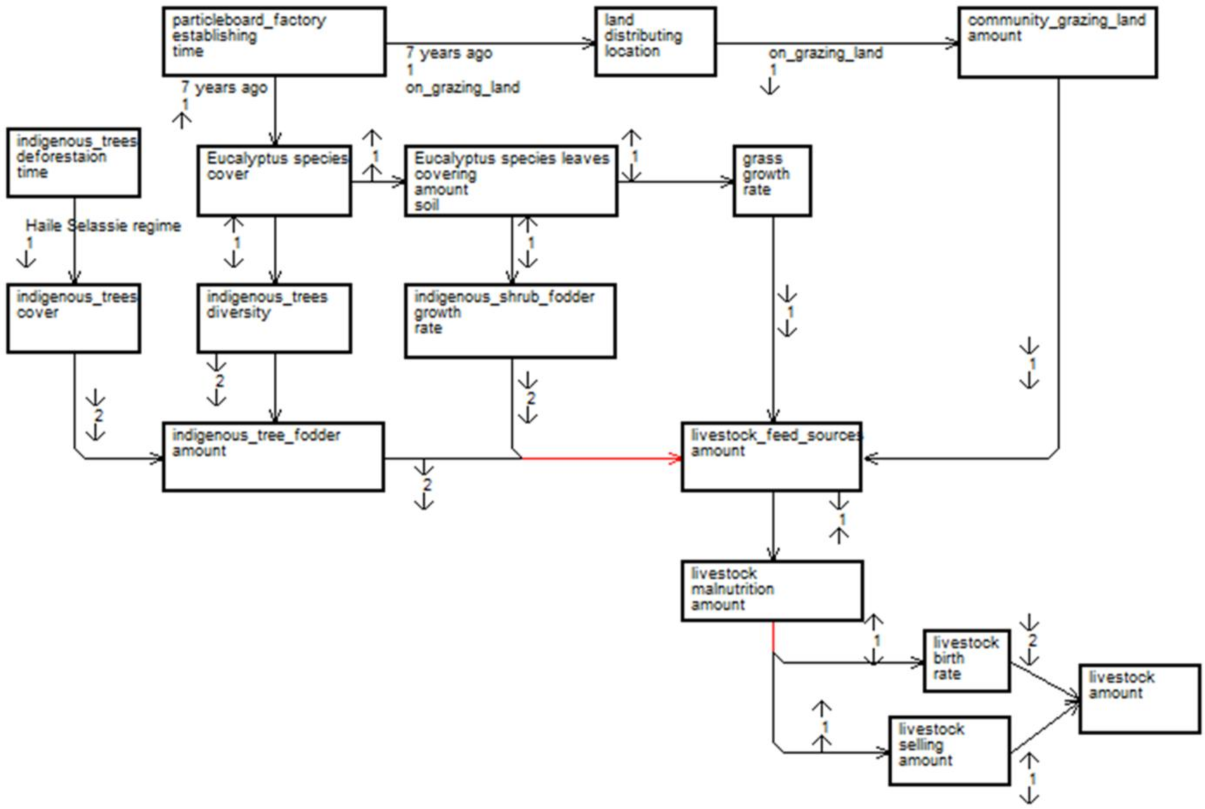

Figure 11 Causal diagram on the impacts of land distribution and land use changes to the availability of and management of livestock feed sources (see Figure 8 for key details).

Exclusion zones were established this year in two pilot areas of Tsibet kebele (around Shemat and Bolonta settlements) and as stated above a patrol has been appointed to guard the areas and prevent livestock from browsing on the seedlings. Fodder trees are being established in these areas to provide livestock feed for the community. Fodder trees are also being planted, with development agent supervision, in newly distributed land in Embahazti kebele where farmer awareness of the need to exclude livestock is strong because of the high level of interventions from the government.

To try and address the need to intensify the utilization of dwindling community grazing land (dwindling because of increasing land distribution), community bylaws were established and tested in both kebeles. There is restricted access to some community grasslands over the rainy season to allow for grass regeneration.

Table 11 Livestock feed source calendar taken from interviews with farmers.

Feed varieties	Niche	Zero Grazing											
		January	February	March	April	May	June	July	August	September	October	November	December
Straw	F												
Weeds	F												
Silage	F, FB												
Fennel	HC												
Tala residue	HC												
Chamaecytisus proliferus	HC												
Pennisetum purparium	IF												
Chloris gayana	IF												
Maize residue	IF												
Wild oats	IF												
		Free Grazing											
		January	February	March	April	May	June	July	August	September	October	November	December
Crop stubble	F												
Grass	CGL												
Shrubs	RS, UL												

KEY: F = Field, FB = Field Boundary, HC = Home Compound, IF = Irrigated Field, CGL = Community Grazing Land, RS = Roadside, UL = Unutilized Land. Shade of green indicates number of times answer was replicated in individual interviews.

	15 - 20
	10 - 15
	5 - 10
	2 - 5
	1
	0

Conclusions for Endamahoni woreda

Fine scale variation of land use and livelihoods

The participatory resource mapping showed a variation in access to resources, and subsequent variation in land use and livelihood systems within the two kebeles and as between them. These variations were most apparent between Embahazti and Tsibet kebeles and in the lower catchment and the upper catchment of both kebeles.

The most significant difference between the upper and lower catchments is access to irrigation which offers farmers in the lower catchment a wider range of marketable crops, a larger number of yields per year and a way to better cope with the changing climate conditions in the area. Small-scale irrigation can therefore provide a key resource to improve livelihoods of households in the lower catchment whilst creative alternatives must be found to improve upper catchment settlements (perhaps with more emphasis on livestock and tree income sources).

The most significant difference found between the two kebeles was the access to and quality of roads. This resource is known to dramatically increase the ease by which farmers can transport products to and from market. Farmers in two of the settlements in Embahazti had asphalt road access and two had seasonal dirt road access. Farmers in two settlements in Tsibet had seasonal dirt road access and two had no road access. Market access is a key consideration when attempting to improve a system by intensification and the limitations of these roads must be addressed in order for the project to be successful.

Another significant difference between the two kebeles was the level of population dispersion. Embahazti had higher dispersion and therefore more home compounds with adjacent fields. Farmers recognised this as a key advantage for planting improved fodder sources as they could be better protected from livestock. Therefore without community mobilisation and strategic livestock exclusion zones there are significant limitations to the introduction of improved feed in Tsibet kebele.

The differences show that there is not a generic set of solutions to be found in these sites and in order to successfully address sustainable intensification of the farming system technologies chosen must be wide ranging and adaptable in order to accommodate local fine-scale variation.

Functions and services of trees

There was found to be a limited function of trees in this study site because of the limited distribution of natural trees and because of the restrictive local bylaws which prohibit cutting or felling outside of particleboard and private land. The bylaws determine that the primary function of tree cover, with the exception of eucalyptus, is as soil conservation on steep, uncultivable slopes. Eucalyptus and some small number of apple trees provide income. Farmers know about their tree and shrub species and about their potential wide range of services but bylaws limit the extent to which farmer's knowledge informs their use of trees and shrubs. Fuel and fodder can be obtained from grass and shrub species which can grow under an open forest canopy. The dominant forest types in this area are eucalyptus and *Cupressus lusitanica* and these trees repress the growth of the grass and shrub species. Eucalyptus trees heavily dominate the area and provide little room for fuel or fodder because of its competitive attributes. Interventions could however be used to target cupressus community plantations which currently serve no purpose to the community and could be converted into bio-diverse natural forest with a more open canopy to allow shrubs and grasses to naturally establish and be utilized.

The niches on private land for planting trees are limited whilst the open grazing system remains. With better understanding of the advantages of intercropping leguminous trees on cropland farmers may be convinced to redress this.

Key constraints to productivity across the site

- The small field size
- Labour constraints on row planting
- Continuous cultivation of fields with no fallows
- Insufficient livestock manure to cope with fuel/fertility trade off
- Heavy reliance on chemical fertilizers which fluctuate in cost
- Soil erosion
- Insufficient fuel
- Insufficient quality and quantity of livestock feed

Recommendations for Endamahoni woreda

Community knowledge exchange and transferability of Sustainable Intensification technologies

- Knowledge gaps in effective management of mixed cropping systems for provision of fodder and the use of multi-purpose trees which are recognised, if not well utilized, by the community – Abreha we Atsbeha (Africa RISING quick wins site) provides a useful location for farmer exchange visits (similar farming system with leguminous tree intercropping)
- Build on the existing practice of utilising volunteer grass weeds (especially wild oats) which are collected from cropland and fed directly to livestock or made into silage.
- Crop rotation is practiced by small numbers of model farmers – if it is to be more widely adopted farmers will need community knowledge exchange
- Green manure management as a supplement to livestock manure to increase household production of organic fertilizer could be better understood so that it becomes more widely used as a supplement
- Row planting and target application is practiced only by a small subset of model farmers. Even with the labour constraints noted by farmers, the advantages of this method require time and knowledge exchange in order to help farmers weigh the benefits
- Optimum fuel source management is needed especially for seasoning and storage requirements so as to more effectively utilize existing resources

Many of the traditional sustainable intensification techniques found in this study arise through the interaction of trees, crops, water and livestock within the mixed farming system about which farmers have important and relevant knowledge. Other intensification techniques such as row planting, crop rotation and manure application are only partially disseminated within the community and are heavily dependent on additional labour - thus making labour a key consideration in their uptake.

Successful uptake of sustainable intensification technologies and management practices must be compatible with and build on existing local perceptions of sustainability. During the feedback focus group discussions with the farmers discussions revolved around the local perceptions of sustainability. Farmers identified the following requirements needed to achieve food and water security and then to sustainably intensify their farming systems.

Community level interventions

- Increasing species diversity and natural vegetation in community forests to reduce shading and increase fuel and fodder grass resources in the understory - this is especially relevant to the cupressus community plantations which have little undergrowth and serve no purpose to the community
- Expansion of exclusion zones in community forest to increase replanting and natural regeneration of trees, shrubs and grasses - the current area which is under livestock exclusion is insufficient to provide cut and carry material for the whole community

- Enforcement of existing bylaws restricting access to community grazing land over rain season to allow grass recovery
- Negotiation with the particleboard company on the placement of Eucalyptus around water sources to reduce negative effects on headwaters and increase water security in the Meta watershed (Embahazti kebele)

Ideas for household level interventions

- Mobilization of community over free-grazing on cropland with pilot exclusion zones for soil and water conservation/ improved feed planting
- Piloting intercropping techniques with compatible and multi-purpose tree species on land with erosion issues and land adjacent to riverbanks (*Sesbania sesban, Chamaecytisus proliferus*)
- Increasing niche utilization (such as home compound) for fuel and fodder sources
- Increasing crop diversity and crop rotation methods with training and improved seed to avoid field exhaustion
- Address labour issue to increase uptake of row planting with a mechanized or efficient method of sowing the seed and/or weeding
- Increasing compost utilization through training on proper storage